

Preparation and further study of the Singa skull from Sudan

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Synopsis

Preparation of the Singa calvaria has permitted study of further morphological and endocranial details. Preparation techniques are described, including the use of acetic acid and ethanolamine thioglycollate, and the specimen was examined for signs of pathology which might account for the unusual cranial shape and diploic thickening. The meningeal vessel patterns and endocast are described, and it is suggested that the Singa individual may have been left-handed. This study provides further data in support of the recent view that the Singa specimen represents an archaic rather than anatomically modern population.

Introduction

The Singa calvaria was discovered in 1924, eroding out of a caliche deposit within the 'Gezira clay' exposed in the west bank of the Blue Nile (Oakley, Campbell & Molleson 1977). Assessments of associated faunal and archaeological materials at Singa and the related site of Abu Hugar have favoured a late Pleistocene age for the specimen (see discussion in Stringer 1979), but recent archaeological work in the area suggests that the skull may have been associated with a Middle Stone Age or even final Acheulian industry, with a probable minimum age of early Upper Pleistocene (Bräuer 1984). The specimen has received comparatively little attention since the first description in 1938 (Woodward 1938) and, as summarized by Stringer (1979), views of its affinities have ranged from workers who classified it as a 'proto-Bushman' (e.g. Woodward 1938) to those who regard it as quite distinct from anatomically modern humans (Brothwell 1974, Stringer 1979). Brothwell (1974) raised the possibility that the unusual cranial shape and proportions of the calvaria were partly pathological in origin, a view supported by Stringer (1979). In the latter paper the hope was expressed that the specimen could be further prepared in order to allow study of endocranial features for the first time, and this has now been achieved.

Preparation of the specimen

When the calvaria was passed to the Palaeontology Laboratory at the British Museum (Natural History), all that was initially required was the removal of approximately 45 g of matrix for dating purposes. In order to obtain this quantity of matrix it was necessary to use a larger opening than that of the foramen magnum. On closer examination of the skull it was seen that at one time most of the occipital region had been broken and then glued back into place. By dissolving the glue and removing the pieces of bone a roughly circular opening about 100 mm in diameter was produced. This opening proved to be an acceptable size through which to work. Once the matrix sample had been removed the next logical step was to take advantage of the situation and prepare the whole of the endocranial surface.

Methods

The first task was in finding a suitable solvent for the glue holding most of the occipital region together. The glued areas were brushed with solvents such as water, industrial



Fig. 1 Inferior view of the Singa cranium before preparation but after removal of rear of vault.

methylated spirit, methyl ethyl ketone and acetone. Only the latter proved to be successful in dissolving the glue and gradually most of the occipital region was successfully detached. These detached pieces were mechanically prepared using a pneumatic engraver, the Desoutter V.P.2, and matrix required for dating purposes was removed using the same tool. Before further treatment was carried out a series of photographs (Figs 1, 3) were taken of the skull for record purposes.

The skull was found in a limestone concretion within the 'Gezira clay' of eastern Sudan (Oakley *et al.* 1977), so it was decided that the safest method of preparation, bearing in mind any fragile structures which could be present, would be to dissolve the limestone matrix chemically, using dilute acetic acid. This organic acid, when used as a dilute aqueous solution, dissolves limestones and breaks down other rocks cemented with carbonates, but it does not react with the phosphatic material constituting the skull (Rixon 1976).



Fig. 2 As Fig. 1, but after final preparation. Note great development of sphenoidal sinus visible through damage on the left side (= right side in this inferior view).

The skull was fully immersed initially in a 1% (v/v) solution of acetic acid in water for about one hour. A low concentration of acid was used in the first instance to gauge the reactivity of the bone and matrix with acid and to provide preliminary cleaning. The skull was then removed from the acid and placed in a small tank with running tap water for 2–3 hours to rinse out the remaining acid and its salts. (Washing time should be at least three times as long as acid immersion time; this is necessary to discourage the growth of calcium acetate crystals during drying, which would disrupt the fossil bone.) During the washing phase, loosened sediment was removed by gently streaming water at the specimen through a pipette. Areas of bone which were too delicate to be cleaned whilst wet were treated after drying in an oven at approximately 50°–60°C for about 24 hours. The whole skull was then cleaned both internally and externally by brushing with methyl ethyl ketone. Exposed bone was then coated with a dilute solution of polybutyl methacrylate (Vinalak 5911) in methyl

ethyl ketone, in the proportion 1:4 v/v. This consolidant was used because of its resistance to acid attack and the fact that it does not swell in water.

When the polybutyl methacrylate solution had dried the skull was immersed in a 3% aqueous solution of acetic acid for about 3 hours and note taken of the extent of reaction. The skull was then washed in running tap water for about 9 hours and subsequently dried in a warm oven as previously described. Any areas of newly exposed bone were cleaned and coated with the polybutyl methacrylate solution. The whole treatment, including 2 hours acid immersion, washing, drying and consolidating was repeated 5 times with a 5% aqueous solution of acetic acid. The acid concentration was increased to speed up the solution of the matrix, but without causing violent effervescence which would have damaged the bone. This concentration of acid was used through the rest of treatment. The immersion time was kept to about 2 hours and washing usually continued overnight.

At this stage of treatment the posterior and anterior clinoid processes were becoming visible and to a slightly smaller extent the lesser wings of the sphenoid bone could be seen.

The grey-brown colour of the bone and red-brown colour of the matrix indicated the probable presence of iron minerals. To help remove these iron minerals and so perhaps aid preparation, a different chemical treatment was tried. This involved immersing the skull in a 5% (v/v) solution of ethanolamine thioglycollate in water for 3–4 hours. The skull was then washed overnight.

Solutions of thioglycollic acid and thioglycollates have been used for derusting iron and steel (Krockow 1966), and have found application in the treatment of fossils for the removal of haematite and limonite matrices (Howie 1974). Ethanolamine thioglycollate, i.e. an aqueous solution of 40% thioglycollic acid containing ethanolamine, will react non-violently with soluble and insoluble iron compounds forming a violet-coloured soluble ferri-thioglycollate complex. During immersion of the skull in the ethanolamine thioglycollate solution this violet complex was formed, confirming the presence of iron. After immersion and washing the skull was allowed to dry in air. Short immersion times and thorough washing were imperative to help prevent the violet-coloured complex ferri-thioglycollate anion from oxidising to a brown insoluble precipitate which would have covered the skull.

After drying, the skull was examined. The overall colour of exposed bone had changed from grey-brown to off-white, giving the skull a bleached appearance. It was therefore concluded that the original colour was mainly due to the presence of iron compounds. The matrix was also found to be 'crumbly' on the surface and was simply removed by brushing. Later analysis of the matrix for iron, by the atomic absorption method, showed a 1% by weight of iron, present as 1.13% Fe_2O_3 and 0.30% FeO .

The acetic acid treatment was then repeated five times, at which stage the exposed endocranial surface was examined. Cracks had appeared in the fragile posterior clinoid process and a hole had appeared in the posterior fossa leading out through the orbital part of the right frontal bone. A cynoacrylate cement (Powabond 240) was dripped carefully into the smaller cracks and the hole was sealed with an acrylate-based filler, composed of polymethylmethacrylate powder (North Hill Plastic) 4.5 parts (w/w), glass beads (vacu beads) 4.5 parts and sepiolite (magnesium trisilicate) 1 part. Methylmethacrylate monomer (North Hill Plastic) was added to the mixture to initiate curing just before it was used. The glass beads and sepiolite were used in the mixture to counteract shrinkage (Croucher & Woolley 1982). Photographs of the skull were again taken at this stage for record purposes. The skull was then treated a further five times in acid and note was taken between treatments of any changes occurring in the condition of the skull. It was observed that new areas of bone, untreated by ethanolamine thioglycollate but exposed by the acid, were grey in colour. Therefore to a limited extent the progress of matrix removed could be monitored between acid treatments by any increase of the grey areas, indicating newly-exposed bone. The skull was then once more immersed in a 5% solution of ethanolamine thioglycollate, as previously described, to whiten newly-exposed bone.

Areas around the temporal bone proved most difficult to clear, so holes were drilled mechanically from the outside through the matrix in the foramen ovale. A 5% acetic acid



Fig. 3 Posterior view of Singa endocranial surface before preparation.

solution was dripped from inside the cranial cavity and drained to the outside through the drilled holes. This process was carried out for approximately 2 hours, by which time most of the matrix had been removed. The whole skull was then washed for 5–6 hours and allowed to dry. Acid immersion was then carried out twice more, after which it was decided to cease acid preparation. After the second immersion the washing procedure was extended to about 24 hours and the skull was finally washed in deionized water.

On examination of the endocranial surface it was found that most of the matrix had been removed except for a small area on the cribriform plate and near the temporal bone. It was decided that further chemical preparation could bring about damage to the finer structures exposed and also the regions in which matrix remained (mentioned previously) were at an almost impossible angle to prepare mechanically.

Both the internal and external surfaces of the skull were coated with a thin layer of the polybutyl methacrylate solution used previously. A final set of photographs were taken at this stage for record and comparison purposes (Figs 2, 4). The repaired occipital region was then almost fully immersed in a 5% solution of ethanolamine thioglycollate as before to whiten the bone. A small area was intentionally not immersed and marked to indicate that it had undergone no chemical treatment. This area could then be used in future to obtain bone samples for dating. An endocranial cast was made by R. J. Parsons before the repaired,

treated occipital region was replaced and cemented with a cynoacrylate cement (Powabond 240).

Palaeopathological aspects

The shape of the Singa skull vault is characterized by an unusual width at the parietal bosses. This increased width is associated with a corresponding increase in the table thickness of the parietal bones (Figs 3–4). Direct measurement of the mid-parietal area at euryon (the points marking the maximum biparietal breadth of the skull) shows a total skull thickness of 14 mm. Is this within the normal range of variation in skull thickness? Measurements on skulls of modern white Americans by Todd (1924) indicate that the average thickness at euryon is 3.56 mm. According to Ethier (1971) some degree of cerebral underdevelopment or a systemic disease, active or healed, should be suspected if the thickest part of the vault exceeds 10 mm. However, some early hominid skulls are known to be considerably thicker than those of modern humans; a thickness of over 10 mm is not unusual (Weidenreich 1943). Certain areas of the skull have also been found to be proportionately thicker than others, particularly the parietal tuberosity in *Homo erectus*. Skulls of Neanderthals are somewhat thinner, but still thicker than the modern average.



Fig. 4 As Fig. 3, but after final preparation. Note in Figs 3–4 the locally great thickness of the parietal bone revealed by the removal of the rear of the vault along an old fracture line.

If the antiquity of the Singa skull is at least early Upper Pleistocene, then possibly the thickening in the parietal region is not outside the normal range of variation of hominids at that time. The vault thickness of the specimen is generally marked, ranging from 7 mm on the parietals and occipital near asterion to 15 mm at inion. Thickness at the midfrontal, bregma and lambda is c. 9 mm, and therefore midsagittal vault thickness is certainly high compared with many Neanderthals. Moreover the thickness at the parietal tuberosity on each side is outside the Neanderthal range and is matched only by the thickest *H. erectus* crania. However, total skull thickness by itself is a poor criterion for assessing the presence or absence of pathological change. Any number of factors including age, sex and individual variation can have an effect on total skull thickness. Normal skulls may be either 'diploic' with a prominent middle table or 'compact' with very little diploic bone (Ethier 1971). In either case the ratio of compact to diploic bone remains about the same; that is a diploic skull will have a correspondingly thicker layer of compact bone. The thickness of the normal skull will always be proportionate to the width of the middle table. Alterations in the normal ratio of compact to diploic bone are a much more significant sign of pathological change.

Weidenreich (1943) did not find an abnormal ratio of compact to diploic bone associated with skull thickening in early hominid material. He found that all three tables of the skull vault were almost equally involved in the thickening, with the inner and outer table contributing slightly more to the overall thickness than the diploe. This is not the case with the Singa skull; the diploe contributes much more to overall thickness than the compact bone. Measurements of the parietal bone show the ratio of compact to diploic bone to be 1:3.9. Data from modern individuals show that the normal ratio of compact to diploic bone in the parietal area averages 1:1.4 (Reynolds 1962). The diploic width of normal individuals was considered to be less than 2.3 times the combined width of the inner and outer table (Reynolds 1962, Sebes & Diggs 1979). The diploic bone in the parietal area of the Singa skull is almost four times the width of the compact bone, which is outside the normal range in modern individuals, and is quite unlike the pattern found in earlier hominids.

Hyperostotic changes of the middle table of bone are usually manifestations of metabolic or developmental diseases (Ethier 1971). Anaemias, in particular, are known to be the most common cause of an increase in the middle table of bone. Anaemias are also known to be associated with changes in vault shape similar to that seen in the Singa skull. As a result it was decided to test the hypothesis that the vault shape and diploic thickening seen in the Singa skull are the result of an anaemia.

On the basis of observations of clinical radiographs of patients with anaemia several criteria have been developed for comparative use with anthropological material (Stuart-Macadam 1982). These criteria represent changes which develop because of the body's basic adaptive mechanism to anaemia: an increase in bone marrow cells. A great increase in the red marrow can produce pressures on the adjacent bone which result in many of the bone changes associated with anaemia. Taken individually, the criteria may occasionally be present on radiographs of normal skulls, but as a group they illustrate a pattern of bone change seen in anaemias with erythrocytic hyperplasia. The seven criteria are:

(1). 'Hair-on-end' trabeculation: the normal circumferentially laid down bony trabeculae radiate out at a 90° angle to the bony tables. This appearance has been found in approximately 5–10% of clinical cases of anaemia.

(2). Thinning of the outer table: the pressure of the expanding marrow can cause a thinning or even disappearance of the outer layer of compact bone as seen on a radiograph. In clinical cases this change has been found in 20% to over 90% of patients with severe anaemia.

(3). Texture changes. Instead of the normal homogeneous pattern of trabeculae seen on a skull radiograph, a coarse, granular pattern with an increase in radiolucency can occur. In clinical studies this has been noted in 25–50% of skull radiographs of patients with various anaemias.

(4). Diploic thickening: this has often been noted in cases of anaemia but has rarely been

quantitatively assessed. The diploe has been considered to be abnormally thickened if it exceeds 2.3 times the combined width of the inner and outer tables of bone.

(5). Orbital roof thickening: this is apparent on examination of the orbital roof on lateral radiographs. It has not been quantitatively assessed in clinical studies but is not an unusual occurrence in cases of anaemia. A thickness of over 3 mm is considered to represent abnormal thickening of the roof (Stuart-Macadam 1982).

(6). Orbital rim changes. Normally the orbital rim on a posterior–anterior skull radiograph shows as a distinct, continuous radiopaque curved line. Although it has not been noted in clinical studies, observations of radiographs of patients with severe anaemia show that the rim can develop an increase in radiolucency and appear thinned, flattened or even obscured (Stuart-Macadam 1982).

(7). Sinus height. Clinical studies have shown that in some case of anaemia, marrow overgrowth can retard or even completely inhibit normal sinus development (Caffey 1978, Reimann *et al.* 1975). In these cases, reduction in normal frontal sinus height or even a total lack of development can occur.

Posterior–anterior and lateral radiographs of the Singa skull were taken (125 kV, 160 mA for 2.5 seconds, using Agfa Gevaert Structurix film which was manually processed; focus to film distance 91 cm). Observations showed that with the exception of the diploic thickening of the parietals, the Singa skull did not exhibit any of the other radiographic criteria associated with bone changes in anaemia. There was also no sign of porotic hyperostosis; these porotic lesions of the orbit and skull vault are commonly accepted as osteological evidence for anaemia. On the basis of these results there is little to support the hypothesis that anaemia was responsible for the unusual shape and diploic thickening seen in the Singa skull. It could even be argued that these features are within the normal range of variability expected for the whole population. However, we feel that the cranial shape, abnormally short parietal length, diploic thickening and extensive sphenoidal sinus development are unusual features both for archaic and modern Upper Pleistocene hominids, and deserve further investigation.

Morphological features of the calvaria

Preparation of the specimen has revealed new external and internal details. The robusticity of the temporal bone in the area of the root of the zygomatic process can be seen more clearly, but further study suggests that the reported prominence of the occipitomastoid crest (Stringer 1979) is more a reflection of the small size of the mastoid process than a significant morphological feature. One of the most notable features of the prepared base is the marked development of the sphenoidal sinus (Figs 1–2). Preparation of the specimen has also allowed clearer radiographs to be obtained and these show a fairly large frontal sinus as well, consisting of two simple lobes on each side, the most lateral extending to above the mid-orbit. The occipital bone can now be seen to show a typically ‘modern’ pattern of venous sinus drainage, and endinion is positioned close to external inion.

Endocranial morphology

The endocranial surface is well preserved, and allowed the preparation by R. J. Parsons of an endocranial cast of silicone rubber with plaster internal support (Figs 5–6). Three determinations of endocranial volume by water displacement each gave values of 1340 ml, which compares closely with a determination by millet seed of 1335 ml. These figures are lower than those estimated previously by calculation or partial endocranial volume determinations (Stringer 1979). While the newly-determined endocranial volume of Singa is typical of modern values, it is low compared with means of Upper Pleistocene samples such as the European Neanderthals (1510 ± 150 ml, $N = 6$), the Skhül-Qafzeh hominids (1545 ± 27 ml, $N = 5$) or European early Upper Palaeolithic hominids (1577 ± 135 ml,



Fig. 5 Left lateral view of endocranial cast, $\times 0.83$.

$N = 11$) (data from Trinkaus, 1983). However, the Singa value is larger than those obtained for hominids such as Djebel Irhoud 1 (1305 ml, Holloway 1981*b*) or a Ngandong sample (1151 ± 99 ml, $N = 5$, Holloway 1980).

The endocranial mould preserves little sulcal or gyral relief, but the meningeal vessel patterns on both sides are clear, relatively simple, and asymmetrical. On the left side (Fig. 5) there is a strong anterior (bregmatic) branch which follows the course of the coronal suture,

Table 1 Endocast indices; comparative data from Holloway (1980, 1981*a, b*).

(Sample)	<i>Austra- lopithecus</i> (4)	<i>H. erectus</i> Java (6)	Ngan- dong (5)	Spy 1 (1)	Spy 2 (1)	Irhoud 1 (1)	Singa (1)	Modern (4)
Breadth/length	0.78	0.79	0.77	0.82	0.78	0.82	0.85	0.78
Breadth/height	1.13	1.28	1.25	1.24	1.20	1.29	1.31	1.08
Length/height	1.44	1.62	1.61	1.52	1.54	1.58	1.54	1.40
Bregma-lambda arc/chord	1.08	1.04	—	1.05	—	1.05	1.08	1.09
Bregma-asterion arc/chord	1.18	1.20	—	1.24	—	1.23	1.25	1.23
Height ³ /volume	1.24	0.97	0.98	1.20	0.93	0.99	0.94	1.25
Breadth arc/chord	1.55	1.60	—	—	—	—	1.58	1.72



Fig. 6 Superior view of endocranial cast, $\times 0.83$, showing unusual left frontal–right occipital petalial pattern, perhaps indicative of left-handedness.

and well-developed middle and posterior branches which originate virtually together above the temporal lobe. On the right side there is again a strong vertically orientated anterior branch, but posteriorly there is only a single branch originating above the main development of the lateral sulcus. This branch crosses the mid-parietal area and gives rise to a subsidiary superior branch after about 15 mm. The posterior part of the parietal appears to have been drained by a separate and inferiorly placed vessel which runs across the posterior part of the temporal lobe.

In general dimensions the Singa endocast is short (frontal–occipital poles, 166 mm, left and right sides), moderately flattened sagittally (dorsal arc, 233 mm both sides), very broad and

flattened (biasterionic breadth 111 mm, temporal breadth 141 mm, arc 223 mm), and rather low (height 108 mm). Additional dimensions measured are bregma-lambda chord and arc, 89.5 and 96.5 mm, and bregma-asterion chord and arc 126 and 158 mm (left side), and 128 and 160 mm (right side).

The proportions of the endocast are more similar to those of non-modern hominids, even including *H. erectus* specimens, than to those of a small modern sample measured by Holloway (Table 1). It is particularly in indices reflecting the relative breadth of the endocranial cast that the Singa specimen appears distinct from the modern endocasts, and assuming that pathological aspects have not played a major part in determining endocranial proportions, this provides further evidence that the Singa calvaria may not represent an anatomically modern specimen (Brothwell 1974, Stringer 1979).

The endocast also shows some interesting structural asymmetry. As discussed in Galaburda *et al.* (1978) and Holloway (1980, 1981*a, b*), human endocranial surfaces tend to show a characteristic asymmetrical development of localized depressions (petalia) which can generally be related to handedness in living individuals. The characteristic petalial pattern for right-handed individuals is that they show left occipital and right frontal petalias, related to the larger volume of the equivalent brain lobes. Holloway has recognized this same combination of features in various fossil hominid endocasts representing *H. erectus*, Ngandong, Djebel Irhoud, Salé and Neanderthal individuals. However, the Singa endocast shows a clear right-occipital, left-frontal petalial pattern, whether viewed superiorly (Fig. 6) or inferiorly. This unusual morphology may indicate that the Singa individual was left-handed.

Concluding remarks

Preparation of the Singa calvaria has allowed study of certain morphological and endocranial details for the first time. While a specific pathological disorder has not been identified, it is still suspected that the diploic thickening at the parietal bosses and perhaps also the sphenoidal sinus development and certain cranial and endocranial characteristics may be due to a pathological cause. The robusticity of the specimen, the simplicity of the meningeal vessel patterns, and the endocranial proportions all support the view that the Singa calvaria represents an archaic rather than a more recent human population.

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